Factsheet
Botanical Data: Yacón

***Smallanthus sonchifolius* (Poepp.) H. Rob.**

Project

Drafting botanical monographs (factsheets) for five Peruvian crops

Factsheet – Botanical Data: Yacón – Smallanthus sonchifolius (Poepp.) H. Rob.

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I. BOTÁNY

Genus. *Smallanthus* belongs to the Asteraceae or Compositae family and is currently made up of twenty-one species that used to be part of the genus *Polymnia* (48, 49, 50, 67, 68, 69). Distribution of *Smallanthus* is restricted to the Americas, and its center of diversity is in Central America and the Andes. Its species are, for the most part, perennial herbs; very rarely are they bushes or small trees. Only one is annual (17).

Genus is characterized by surface (with slight indentions) and shape of the achenes (radially thickened and laterally compressed), venation (almost always tri-nerved or palmate), presence of one whorl on the outside of the phyllaries, lack of glands at the tip of the stamen, and shape of the hair on the corolla (with an acute tip).

Morphology: *S. sonchifolius* is a perennial herb that grows up to 1.5 m – 3 m in height and whose stem is cylindrical to angular, lined, hollow in maturity and densely pubescent at the apex (17, 67).

Root system is formed by a rather ramified arrangement of adventitious roots and up to twenty fleshy, tuberous storage roots. The latter develop from a ramified system of subterranean rootstock, are primarily napiform, and can grow up to 25 cm in length and 10 cm in width and weigh between 0.2 kg – 2.0 kg. Root bark and storage tissue color vary depending on clone: white, cream, pink (grooved), lilac, and even brown.

Leaves are opposites with blades decurrent towards the petiole. Leaf blade is broadly ovate and hastate, connate or auriculate at the base; upper leaves are ovate-lanceolate; upper surface is hairy and the lower pubescent. Inflorescences are terminal, composed of 1 – 5 axes, each one with 3 capitula; peduncles densely pubescent.

Phyllaries are uniseried and ovates, up to 15 mm in length and 10 mm in width. Inflorescences (head) are yellow to orange with close to 15 ligulate flowers, which are female, have 2 or 3-teeth, and grow to 12 mm x 7 mm; disc flowers are male, about 7 mm long. Achene is, on average, between 3.7 mm – 2.2 mm (55), ellipsoidal, dark brown colored, with a smooth epidermis and a solid endocarp characterized by easy removal of the pericarp by slight rubbing. Some ecotypes do not produce fruit and, if so, they are not viable (47).

Taxonomy: Work carried out on *Smallanthus* (or *Polymnia*) systematics has been almost entirely done on herbarium specimens. At issue here is their reduced size and less than satisfactory quality caused by plant structure and size and limited access to most of the natural distribution areas. For instance, they generally lack subterranean organs (48, 67) and, consequently, determining South American species is not an easy task (17).

A new critical study of South American representatives of the genus is unquestionably necessary.

Variability: Farmers can tell each yacon cultivar apart by stem and storage root color. There is, however, much less diversity in comparison with other comparable, useful plants. Estimates for number of cultivars place the figure somewhere between twenty and thirty (32, 33). Under controlled situations, cultivars (i.e. genotypes) present significant differences in terms of these characteristics: storage root shape and weight, yield, and sugar, phenol, and DNA content as well as leaf isoenzymes (18, 26, 27, 28, 29, 30, 35, 38, 62).

Tello speaks of two phenotypic centers of diversity in Peru: the South, which encompasses the eastern slopes of the Andes found in the departments of Cuzco and Puno, and the North, comprised of the Cajamarca and Contumaza provinces in the department of Cajamarca (60). Seminario et al. discuss finding four morphotypes in the North, set apart by different descriptors such as root color and leaf shape, with type III the most frequent there, especially in zones where yacon is commercially grown (52).

Mansilla furthermore brings up the fact that germplasm banks at the National Agricultural Research Institute (INIA), International Potato Center (IPC), the National University of Cajamarca (NUC), and San Antonio Abad University (SAAU) in Cuzco store 323 yacon clones; these institutions have also identified thirty-five different morphtypes: 9 at INIA, 10 at IPC, 8 at NUC, and 8 at SAAU. Based upon his study, he was able to conclude the central part of the country is where the greatest diversity is found (34).

II. DIAGNOSTIC FEATURES AND POSSIBLE CONFUSIONS............................

Besides *S. sonchifolius*, there are six other *Smallanthus* species recognized in Peru (5). Two of these (*S. riparius* (H.B.K.) H. Rob. and *S. siegesbeckius* (DC.) H. Rob.) are deemed to belong to the same group as yacon (a.k.a. "yacon group") and are closely related to *S. sonchifolius* due to distribution, habit, and morphology (17).

Consequently, diagnostic features used by Wells are not always easy to interpret (see Table 1) (67), but, because yacon (or llacon) only reproduces vegetatively and is not harvested in wild populations, there is no real risk in confusing it with other species.

Table 1: Diagnostic features of Peruvian *Smallanthus* species within the "yacon group" (67)

Feature	***S. siegesbeckius***	***S. riparius***	***S. sonchifolius***
Disk flowers **Tubular flowers**	Number ≤ 15	Number ≥ 30	Number ≥ 60
Ligulate flowers	5 – 6 mm long	≥ 10 mm long	ca. 12 mm long
Phyllaries	≤ 1 cm	≥ 1 cm	≤ 15 mm long and ≥ 10 mm broad
Palea	Involute margin		Non-involute margin

III. Distribution

Worldwide distribution. As of today, *S. sonchifolius* is distributed throughout most of the Andean territory, either in the wild or in cultivation, from Ecuador in the North to northeastern Argentina in the South (17, 20, 55). There have even been sporadic reports of it in Colombia and Venezuela (41, 45, 67, 72).

Its center of diversity is between the Apurimac watershed in southern Peru (14ºS) and La Paz, Bolivia (17ºS), zone where the greatest genetic diversity is found as well as three of the most closely related wild species. There have been attempts in the last thirty to forty years at cultivating it outside its natural distribution, some even on a massive scale, mainly in New Zealand, China, Russia, Taiwan, Japan, South Korea, Brazil, and what used to be Czechoslavakia (10, 30, 33).

Distribution in Peru. Yacon cultivation in Peru has been reported in eighteen Andean departments (55) with main production areas found in Cajamarca, Puno, Pasco, Huanuco, Ancash, and Junin and to a lesser extent in Piura, Amazonas, Lambayeque, La Libertad, San Martin, Lima, Huancavelica, Ayacucho, Apurimac, Arequipa, and Cuzco.

Table 2: Estimates of frequency and distribution of *S. sonchifolius* in Peru, based on herbarium specimens from USM, HUT, HAO, AMAZ, CUZ, HUSA (no specimens from the other Peruvian departments; no reports of wild growth)

Region	# of specimens	# of provinces	Estimated frequency
Ancash	1	1/20	Rare
Cajamarca	1	1/13	Low
Cusco	4	3/13	Low
Huanuco	1	1/11	Low
Junín	1	1/9	Low
La Libertad	1	1/12	Rare

IV. Ecology and possible cultivation

Habitat. The assumption is that yacon and its related species have been grown on the eastern slopes of the Andes in humid regions with moderate temperatures and seasons with an intense dry spell (17).

Growth. Optimal growth is reached in temperatures ranging from 18º C to 25º C, under which leaves can withstand temperatures up to 40º C without visible damage. Low nighttime temperatures in zones of medium elevation produce optimum growth of storage roots, while warmer, lower regions favor greater development of subterranean stem portions or propagules (erroneously called rhizomes). Aerial organs cannot withstand frost and present damage in temperatures below -1º C (17).

Nevertheless, plants are not harmed in areas of mild frosts as long as these occur during the growing season. In New Zealand, temperatures that hover near -7º C kill all subterranean plant organs. Temperatures below 10º C – 12º C with high solar radiation cause leaf damage.

Biological reproduction. Flowering and pollination in yacon is not well known. Generally speaking, flower production is more reduced in yacon than in wild species, a feature commonly present in other clonally propagated useful plants (17). Flowering is strongly dependent on environmental conditions and differs among growing areas. Where conditions are favorable, flowering begins 6 – 7 months and peaks 8 –9 months after planting.

It is assumed yacon cross pollinates, an indication of this being pollen morphology, early growth of feminine flowers (protogyny), feminine flower morphology, and nectar production, especially in disk flowers (55).

Additionally, one pollination study demonstrated seed production in flowers with open pollination is double that of encapsulated flowers (31). Seed production is, nonetheless, quite low in most cases, yet it is not known why. Pollen sterility is assumed to be one of the possible factors, yet available studies are contradictory (16, 56).

Another likely, presumable factor is an imbalance in plant metabolism in which the plant must supply energy to grow a greater number of flowers and for developing storage roots. Proof of this is the larger number of seed formed in flowers that bloom first. Besides, germination rates of less developed seeds are rather low, just 0% - 32% (6, 46).

A possible reason is physical seedcoat dormancy due to its hardness, which is a known feature of one of *Smallanthus'* wild species. Moreover, growth of plants produced by seeds is slower than those that reproduce vegetatively. Yacon flowers can be artificially produced through grafting them onto sunflowers (40).

Photoperiod. Yacon is considered day neutral, at least when it concerns stem and storage root formation (33, 41, 45). Since these processes begin later in higher elevations, Grau and Rea assume it develops storage roots and flowers mainly during short days (17).

Cultivation region. Overall, yacon can be cultivated in temperate and sub-tropical latitudes (0º - 24º) (33), and, while it is possible to do so throughout Peru, from the coast (Lima and Trujillo) to rain forests in low lands, it grows best in altitudes between 1100 m and 2500 m (55).

Yacon cannot be grown in the northern tip of Peru above 3000 m, yet successful cultivation can occur in the departments of Amazonas and San Martin, even in cloud forests (ca. 3600 m). Altitude ranges in other countries suggest a high capacity for adaptation: Bolivia and Ecuador = 900 m – 3500 m, northwestern Argentina = 600 m – 2500 m, Brazil = 600 m, and New Zealand and Japan = sea level.

V. CULTIVATION AND USE

Cultivation. Yacon can be cultivated, but there is practically no known evidence that wild populations are used. In the upper reaches of the Andes, it is planted towards the beginning of the rainy season (between September and October) in order that most of the growing season occurs then. In lower zones, if it is sufficiently irrigated, yacon can be planted and harvested throughout the entire year (33, 55). In dry regions of Peru, where there is no threat of frost, it can also be grown during the whole year as long as there are sufficient levels of available water.

Field preparation depends upon local conditions. For example, planting distances for propagule cuttings can vary: 0.6 m – 1.0 m between plants and 0.8 m – 1.0 m between rows. Planting distance tests run in South Korea suggest a plant density of 30,000 plants /ha(9), with 70 cm between rows and 47 cm between plants.

Likewise, experiences in New Zealand show an increase in yield as density increases to over 24,000 plants/ ha. (10). Plants need a relatively large amount of water during the beginning of the growing season. Accordingly, yacon grown in inter-Andean valleys normally demands irrigation. In Bolivia, it is mostly cultivated in regions with rainfall between 300 mm and 600 mm.

Rainfall ≥ 800 mm is deemed optimum. It is also recommended that rows be hoed during the growing season (45). If rhizome fragments are being planted, then initial plant growth is relatively slow and the shoots will not sprout until after 30 – 50 days. Weed control is usually done only twice after the growing season starts since yacon plants can, naturally, suppress weeds.

Very little research has been done on fertilizing. One test of a cultivar in Brazil showed higher yields are obtained through fertilizing with 140 kg N/ ha and 100 kg K/ ha (1). In Cajamarca, fertilizing with 5 – 10 tons/ ha of humus is enough to balance out nutrient loss (55).

Soil. Yacon grows well in different types of soil, yet the best seem to be light, deep, well-drained, nutrient rich ones (45). These soils favor uniform storage root growth and limit decomposition. Growth is poor in heavy soils. Very good crops are also obtained in sandy river terraces in Bolivia and in lateritic soils corrected with dolomite in Brazil (17). Soil pH can be acidic to slightly alkaline; best results are achieved in pH neutral to slightly acidic soils (32).

Propogation. Propogation is always vegetative and is traditionally done with propagules (shoots), cuttings, and rootstock (44). Propagules (subterranean stem pieces) should be divided so each fragment has somewhere between 3 and 5 sprouts (33, 55). This way, it is possible to get 15 – 35 propagule cuttings per plant per year. Studies in New Zealand, experimenting with planting larger propagules (200 gr instead of 50 g), demonstrated yields per plant were better than double (10).

Storage roots are not able to be propagated. New studies show propagules can be kept underground 25 – 40 days post harvest, after which time cuttings or sprouts can be carefully separated and planted. Doing thus can accelerate cultivation cycle to a certain degree. Propagation through use of stem cuttings (with at least two sprouts) is also possible (17), yet it is best if plants that have not flowered are used, for example, those that are between 5.5 and 6 months old.

Treating yacon with auxins in labs under controlled conditions (saturated atmosphere) produces the best rooting. In the field, nurseries need to be prepared with washed and disinfected (with 10% formalin) river sand so cuttings will remain under wet conditions at least until the first sprouts appear. Hence, 98% - 100% of cuttings root after forty-five days (53).

Propagation using individual sprouts is also possible in greenhouses (54). Here, they are planted into rooting substrate under sterile conditions. After sixty days, somewhere between 43% - 97% take root, depending on the cultivar. The same method can be used with whole stems, where sprouts have to be separated after rooting. In vitro propagation is also possible and of commercial interest.

Several protocols have been developed for it and are related to producing virus free specimens (11, 36, 39, 63, 71).

Pests and diseases. Pests and diseases have not been a large problem in cultivating yacon, so far, mainly because there are no large scale monocrops. Pests do appear in warm, humid regions, and some leaf and root pests and diseases have also been reported (4, 12, 17, 31, 43, 51).

Harvesting and yield. Once growth cycle concludes, aerial parts begin to die, a clear indication that it is time for harvesting. Storage roots may still remain for a time underground without damage, depending on region and climate. Harvesting also depends on region and elevation, usually occurring 6 – 12 months after planting.

Brazilian and New Zealand studies illustrate harvesting every 7 – 8 months is better for yield and fructooligosaccharide content (42, 66, 70). When harvesting, aerial parts must be removed first and then rootstock can be carefully dug up (55). Storage roots are very sensitive to mechanical damage. Later on, rhizomes are separated from storage roots. Mechanical potato harvesters have been successfully employed in Brazil and New Zealand (10, 21). Leaf harvesting occurs when adult leaves form an approximate right angle to the stem.

Initial studies in Cajamarca suppose leaves can be harvested every 30 days, but there is not much known on the extent of the effect leaf harvesting has on storage root production. Average storage root production per ha in upper Andean cultivations is normally between 20 and 40 tons/ ha fresh weight (10% – 14% dry weight). In areas around Cajamarca, it ranges from 40 – 50 tons/ ha (18, 45, 55).

Production largely depends upon cultivar selection, cultivation area (altitude, length of day, soil fertility), tending, and fertilizing. Brazil has even had reports of producing 100 tons/ ha (21). Shorter distance between plants increases yield and storage root proportion (<200) (1, 9, 61). Leaf harvesting is estimated to be around 3 – 4 tons dry weight in fields with densities of 18,500 plants/ ha. The Czech Republic has reported leaf harvests of nearly 2 tons (64).

In addition, studies were conducted on 45 genotypes from germplasm bank collections at the Andean Crop Research Center (CICA) and SAAU Andean Root and Tuber Program (RTA), resulting in average yields of 0.9 kg/ plant (58). In his study of northern ecotypes, Huaman was able to produce an average weight of 1.09 kg/ plant, while Tello, during his test of plants from Huanuco, recorded average weight at 2.85 kg/ plant (19, 60).

Melgarejo, working with local varieties in Oxapampa (Pasco), obtained 3.4 kg/ plant by using high levels of fertilizer. Nevertheless, this is the opposite of Rivas' results that showed plant yield on the "morado piel negro" (black skinned purple) variety to be 1.3 kg/ plant (37, 47). Sotomayor analyzed 101 yacon varieties from northern Peru and separated them into 12 different morphological groups, classifying mainly by stem color, leaf color and shape, root tissue, and propagule color. Average weight is recorded at 0.979 kg/ plant (57).

VII. POST HARVEST ……………………………………………………..

Storage roots accumulate large quantities of fructooligosaccharide (FOS) of the inulin class with a degree of polymerization at 3 – 10 (lower than true inulin) (2, 3, 18, 23, 24). FOS makes up about 10% of fresh weight, translating into 70% - 80% of dry weight. It forms during the growing season from simple sugars and is then enzymatically decomposed again between harvest and sprouting (13, 14, 55). Average degree of FOS polymerization rises during the growing season.

There are some studies showing that post harvest, i.e. when storage roots are in warehouses, FOS concentration decreases and free sugar concentration increases once again. It seems this conversion takes place rather rapidly, especially during the first days after harvesting and in relation to storage conditions (7, 8, 25, 65).

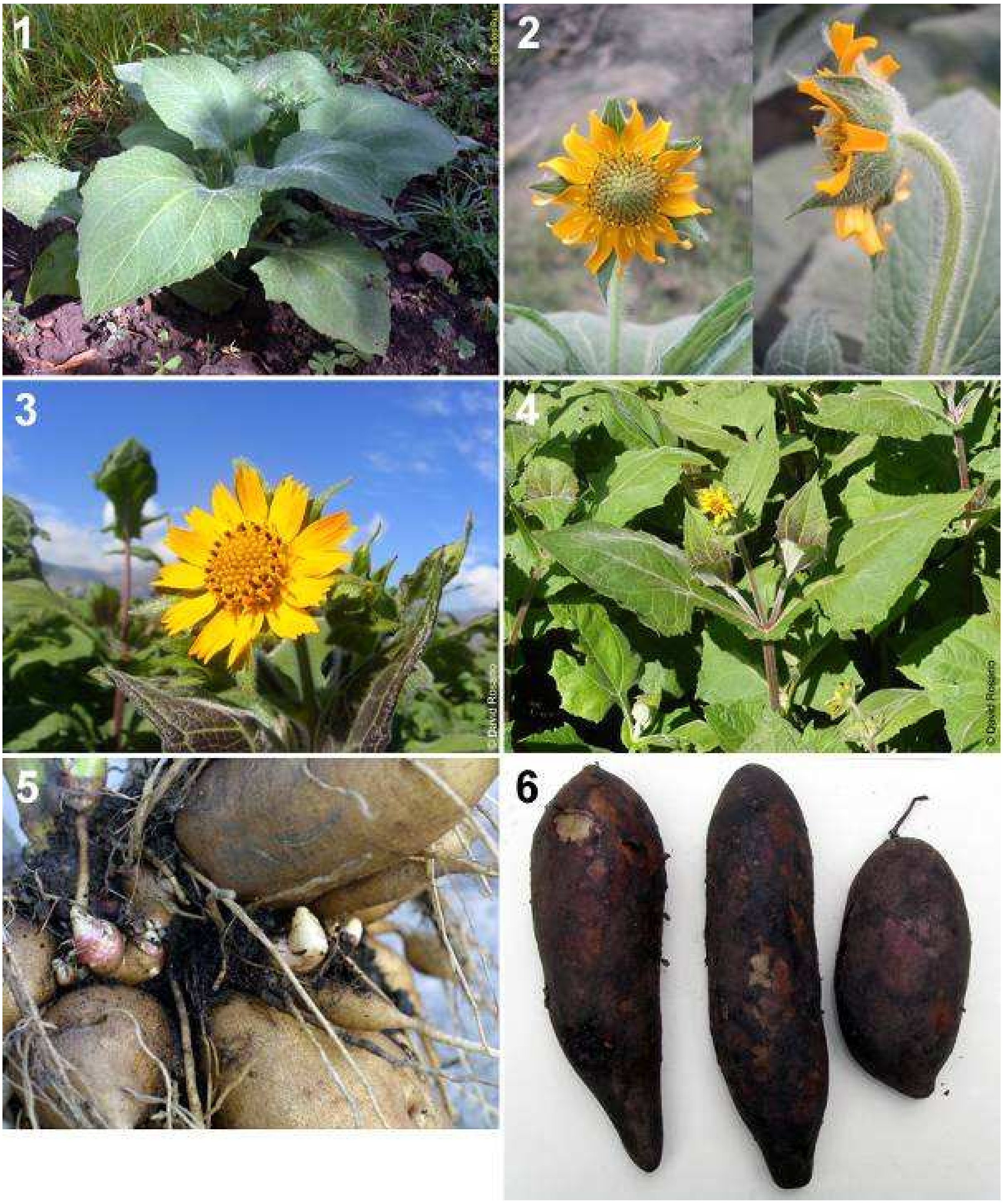
Nevertheless, these studies were restricted to just a few cultivars; thus, warehoused storage root specimens from two different elevations (1990 m and 1930 m) demonstrated FOS content during the first few days diminished to a greater extent in plants from the lower elevation, yet concentration levels evened out after twelve days (15).

Storage roots warehoused in New Zealand for thirty days at 1º C show no changes in FOS concentrations (10). However, there is a steady drop in concentration afterwards, reaching around 35% at day seventy-two. When roots are stored at 5º C, 10º C, 20º C, and at room temperature, a drop of 25% after fifteen days is noted. Yet, FOS degradation has been prevented in root sprouts frozen at -20º C (22).

As well, FOS with lower degrees of polymerization (2 – 7) degrades more quickly than those with a higher degree (9 -11). Storage root and leaf phenol content does not seem to change during warehousing and drying (40º – 60º C) (59).

To make products with high FOS concentrations, storage roots should be kept for short periods in cold, dark places with high humidity and then processed whenever possible. Roots are traditionally left in sunlight for a couple of days after harvesting since they become sweeter this way. One study on this method showed that roots left out for six days present a 40% water loss, 50% - 62% FOS concentration loss, and even 29% - 44% dry weight loss. Free sugars also increase using this method (15).

There have also been visible differences reported on conversion rates between different cultivars. FOS concentration to fresh weight is slightly higher in roots exposed to sunlight for six days than in those having just been harvested due to lower weight. This means absolute FOS quantity is directly greater after harvest and the relative quantity greater after sunlight exposition. Storage conditions should also be selected as to intended product type.



1) Yacon plant; 2, 3: Inflorescence (head); 4) Habit; 5) Root system; 6) Fleshy, tuberous storage roots

Photos: 1: Carlos Ruiz; 2: Lazaro Santa Cruz; 3, 4: David Rosario; 5: Markus Ackermann; 6: Jose Roque.

VII. LITERATURE

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